AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 104:411–425 (1997)

Craniofacial Affinities of Mariana Islanders and Circum-Pacific Peoples

TSUNEHIKO HANIHARA*
Department of Anatomy, Tohoku University School of Medicine, Sendai, Japan

KEY WORDS Micronesia; East/Southeast Asia; multivariate analyses; craniofacial morphology

ABSTRACT Metric craniofacial variation was studied in a number of skeletal samples that originated from the Mariana Islands and circum-Pacific regions. The broad comparisons including East/Southeast Asians, Polynesians, Melanesians, and Australians confirm the relationships between Mariana Islanders and East/Southeast Asians on the one hand and Polynesians on the other hand. A transformation of Melanesians into western Micronesians is not supported. The result of the principal component analysis indicates that the cranial morphological pattern of Mariana people shares the intermediate characteristics between those of typical East/Southeast Asians and several groups falling as outliers to more predominant Asian populations. Am J Phys Anthropol 104:411–425, 1997.

Of all Pacific islanders, Micronesians are undoubtedly the least studied in both morphological and genetic fields of anthropology (Howells, 1973, 1989; Hill et al., 1989; Pietrusewsky, 1990a). In the field of morphological anthropology, the studies of Micronesians have focused on the Guamanians, because the largest skeletal series is from Guam, now housed in the State Museum of Natural and Cultural History (B.P. Bishop Museum) in Honolulu (Pietrusewsky, 1990a).

The investigators of physical anthropology long associated with research in Micronesians and the Pacific peoples, such as Howells (1990), Pietrusewsky (1990b), Turner (1990a), and Brace et al. (1990), reached, in the feature articles of "the physical anthropology of Micronesia" which appeared in the *Micronesica Suppl. 2*, the unanimous conclusion supporting their previous studies of a non-Melanesian source and origins of the Micronesians and Polynesians (Turner and Scott, 1977; Turner and Swindler, 1978; Turner, 1987, 1990b; Brace et al., 1989; Pietrusewsky, 1984, 1985, 1988, 1990c). In addition to these pioneering studies, a good number of investigations re-affirm that Micronesian (and Polynesian) origins are definitely non-Melanesians and from a source farther west (Katayama, 1990; Hanihara, 1992, 1993), while hypotheses on the exact origins and affinities of Micronesians may differ among investigators; Pietrusewsky (1990b,c) and Hanihara (1992, 1993) suggest prehistoric Southeast Asia; Turner (1990a) suggests Borneo, which is part of Southeast Asia; Brace et al. (1989, 1990). Brace and Hunt (1990), and Brace and Tracer (1992) favor the prehistoric inhabitants in Japan, Jomonese; and Ishida and Dodo (1993) find an association with East Asians.

In the field of human genetics, the presence of East/Southeast Asian alleles indicates a significant Asian component in Mi-

Contract grant sponsor: Japanese Ministry of Education, Science, and Culture; contract grant numbers 09208203, 09839003. Contract grant sponsor: Japan Society for the Promotion of Science.

*Correspondence to: Tsunehiko Hanihara, Department of Anatomy, Tohoku University School of Medicine, 2-1 Seiryo-cho, Aoba-ku, Sendai, 980-77, Japan. E-mail: hanihara@anat1.med.tohoku.ac.jp

Received 26 April 1996; accepted 7 June 1997.

TABLE 1. Samples used in the present study

Sample name	N	Brief information
Micronesians		
Mariana	21–77	Prehistoric Chamorros from Guam Island, including recent Saipan and Tinian Islanders (Bishop Museum, Musée de l'Homme)
Caroline	11–26	Recent Ponape Islanders, including a few other Caroline Islanders (Univ. of Tokyo, Musee de l'Homme)
East Asians		
Japanese	30–31	Recent Japanese from around Tokyo (Univ. of Tokyo)
Ainu	35–87	Recent Ainu tribe in Hokkaido, Japan excavated by Y. Koganei in late 1800s (Univ. of Tokyo)
Jomonese	12–108	Prehistoric people in Japan, ca. 5,300–2,300 years BP (Univ. of Tokyo)
Northern Chinese	41–51	Northern part of China, mainly from Liaoning Prefecture (Univ. of Tokyo, Natural History Museum)
Southern Chinese	61–66	Chinese from south of Cheng Kiang River (Natural History Museum,* Musée de l'Homme)
Korean	22–25	Recent Koreans, mainly from South Korea (Univ. of Tokyo)
Mainland Southeast Asians		
Thai	18–30	Recent Thailanders from around Bangkok (Natural History Museum, Musée de l'Homme, Univ. of Sydney)
Vietnamese	22–24	Recent Vietnamese from Tonkin district (Musée de l'Homme)
Early Vietnam	4–20	Neolithic Vietnam, mainly from Tonkin district (Musée de l'Homme)
Laos-Cambodia	21–43	Recent people from Laos and Cambodia (Musée de l'Homme)
Myanmar	87–103	Recent inhabitants in Burma (now called Myanmar) (Natural History Museum, Univ. of Cambridge)
Malayan	43–53	Recent Malayans from Malay Peninsula (Natural History Museum, Univ. of Cambridge, South Australian Museum)
Island Southeast Asians		
Andamanese	45–50	Recent inhabitants in Great Andaman Island, Jarawa tribe and others (probably Andaman Negrito group), including a few samples from Little Andaman Island (Natural History Museum, Univ. of Cambridge, Musée de l'Homme)
Nicobarese	14–20	Recent population from Nicobar Islands (Natural History Museum, Univ. of Cambridge)
Bornean	74–91	Native inhabitants in Borneo Island, mainly from the so-called Land Dayaks, but including Iban tribe (Sea Dayaks) (Natural History Museum, Univ. of Cambridge, Musée de l'Homme, Univ. of Tokyo, Univ. of Sydney, South Australian Museum, Kyoto Univ.)
Filipino	86–95	Recent native inhabitants of the Philippines, Tagalog and other tribes from Luzon and Mindanao Islands (Natural History Museum, Univ. of Cambridge, Musée de l'Homme)
Negritos	17–19	Recent Philippine Negritos, Aeta, Agta, and other tribes (Natural History Museum, Musée de l'Homme)
Greater Sundas	69–75	Recent inhabitants of Java and Sumatra Islands (Natural History Museum, Univ. of Cambridge, Musée de l'Homme)
Lesser Sundas	10–13	Recent inhabitants in Lesser Sunda Islands; Timor, Bali, Sumbawa, and Flores Islands (Natural History Museum, Univ. of Cambridge, Musée de l'Homme)
Moluccas	27–29	Recent inhabitants in Celebes and Molucca Islands (Natural History Museum, Univ. of Cambridge, Musée de l'Homme)
Polynesians		
Hawaii	68–72	Recent Hawaii Islanders; mainly from Oahu (Natural History Museum, Univ. of Cambridge)
Tonga-Samoa	12–20	Recent inhabitants of Tonga and Samoa Islands (Bishop Museum, Natural History Museum)
Marquesas	52–57	Early Marquesans from Uahuka Island (ca. 2000 BP) and recent Marquesas islanders (Bishop Museum, Natural History Museum, Musée de l'Homme)
Easter	49–65	Recent Easter Islanders (Australian Museum, Natural History Museum, Musée de l'Homme)
Society	41–46	Recent Society islanders, mainly from Tahiti (Bishop Museum, Natural History Museum, Musée de l'Homme)
Maori	103–111	Recent aboriginal populations from New Zealand (Australian Museum, Univ. of Sydney, South Australian Museum, Natural History Museum, Univ. of Cambridge)
Moriori	66–70	Recent aboriginal populations in Chatham Island (Australian Museum, Univ. of Sydney, South Australian Museum, Natural History Museum, Univ. of Cambridge)
Melanesia		
Papua New Guinea	111–123	Purari River delta, Fly River delta, Sepik River delta and other region (Australian Museum, Univ. of Sydney, South Australian Museum, Natural History Museum)
Torres Strait	51–60	Recent inhabitants of the islands of Torres Strait (Natural History Museum, Univ. of Cambridge, Musée de l'Homme)

(*continued*)

TABLE 1. Samples used in the present study (continued)

Sample name	N	Brief information
Vanuatu	19–25	Recent inhabitants of New Hebrides (Australian Museum, Univ. of Sydney, South Australian Museum, Natural History Museum, Univ. of Cambridge)
New Caledonia	33–39	Recent New Caledonia Islanders (Australian Museum, Univ. of Sydney, South Australian Museum, Natural History Museum, Univ. of Cambridge)
New Britain	51–58	Recent inhabitants of New Britain (Australian Museum, Univ. of Sydney, South Australian Museum, Natural History Museum, Univ. of Cambridge)
New Ireland	22–26	Recent New Ireland people (Australian Museum, Univ. of Sydney, South Australian Museum, Natural History Museum)
Solomon	45–58	Recent inhabitants of Solomon Islands (Australian Museum, Univ. of Sydney, South Australian Museum, Natural History Museum, Univ. of Cambridge)
Fiji	30–42	Recent aboriginal Fijians (Australian Museum, Bishop Museum, Univ. of Tokyo, Natural History Museum, Univ. of Cambridge, Musée de l'Homme)
Australia		
New South Wales	43–58	Recent Australian Aborigines from coastal region of New South Wales (Australian Museum, Natural History Museum, Univ. of Cambridge, Musée de l'Homme)
South Australia	77–130	Recent Australian Aborigines inhabiting near Adelaide (South Australian Museum, Natural History Museum, Univ. of Cambridge, Musée de l'Homme)
Queensland	18–20	Recent Australian Aborigines from Queensland (Natural History Museum, Univ. of Cambridge, Musée de l'Homme)
Western Australia	16–22	Recent Australian Aborigines from Western Australia (Natural History Museum Univ. of Cambridge)
Murray River	13–45	Roonka Site and recent inhabitants from Murray river basin (South Australian Museum, Natural History Museum, Univ. of Cambridge, Musée de l'Homme)

*Natural History Museum: London, U.K.

cronesians (Omoto, 1984; Ranford, 1989; Serjeantson, 1989). The genetic data on Micronesia have, however, failed to support the link between Micronesia and Polynesia (Serjeantson and Hill, 1989). Several genetic markers indicate, moreover, that Micronesians are a distinct hybrid of Southeast Asian and Melanesian gene pools (O'Shaughnessy et al., 1990; Serjeantson and Hill, 1989; Ranford, 1989). According to Brace et al. (1990), the main support for the view that Pacific islanders arose by differentiation in Melanesia has come from interpretations of linguistic and archaeological investigations (Groube, 1971; Green, 1979; Intoh, 1997).

The discrepancies of the affinities of Micronesians presented from various fields of science indicate that Micronesian physical characteristics may be quite unique. Then, what is the communality in the macro-Asian and Pacific populations? By different approaches, the results seem to differ considerably.

The earliest peopling of Micronesia is estimated by carbon 14 dating to be about 3,500 years BP (Craib, 1983). Ray (1981) reported early Guam occupation at about 3,300 years BP based on radiocarbon analysis. Turner (1990a) obtained a dento-chronological estimate for the settlement of Guam and Micronesia at about 4,000–5,000 years ago. If it is true, as seems likely, the weak affinities of Micronesians with surrounding geographical groups may reflect adaptive responses to different sets of selective forces over a period of time as pointed out by Brace et al. (1990). However, adaptation to environment involved in the phenotype would be hard to test.

The present study focuses on the craniofacial similarity of Micronesians (Mariana Islanders) with the possible populations from whom they may have diverged to elucidate the biological relationships of Micronesians with circum-Micronesian peoples.

MATERIALS AND METHODS

All the crania used in this study were male. The present study includes altogether 42 groups from circum-Pacific regions (Table 1). Although several samples are similar to the skull series used in a recent study (Hanihara, 1994), a good number of new specimens and new measurement items have been added in almost all the series. Standard craniofacial measurements applied to the present analyses were 34 items as shown in Table 2.

In the present study, raw measurement data were converted into Z-scores, which in turn were used to generate C-scores as

TABLE 2. Items measured

General measurements	
Maximum cranial length	(M1)*
Nasion-opisthocranion	(M1d)
Cranial base length	(M5)
Maximum cranial breadth	(M8)
Minimum frontal breadth	(M9)
Maximum frontal breadth	(M10)
Radiculare-radiculare	(M11b)
Maximum occipital breadth	(M12)
Basion-bregma height	(M17)
Sagital frontal arc	(M26)
Sagital parietal arc	(M27)
Sagital occipital arc	(M28)
Sagital frontal chord	(M29)
Sagital parietal chord	(M30)
Sagital occipital chord	(M31)
Facial length	(M40)
Upper facial breadth	(M43)
Bizygomatic breadth	(M45)
Middle facial breadth	(M46)
Upper facial height	(M48)
Interorbital breadth	(M49a)
Orbital breadth	(M51)
Orbital height	(M52)
Nasal breadth	(M54)
Nasal height	(M55)
Maxilloalveolar breadth	(M61)
Mastoid height	(H-MDH)**
Mastoid width	(H-MDW)
Facial flatness measurements	
Frontal chord between the frontomalaria orbitalia	(M43(1))
Subtense of the nasion from the frontal chord	(No. 43c)***
Minimum horizontal breadth of the nasalia	(M57)
Simotic subtense	(M57a)
Zygomaxillary chord between the zygomaxillaria anteriora	(No. 46b)
Zygomaxillary subtense; i.e. the subtense of the subspinale	(No. 46c)

*M = Martin and Saller, 1957; **H = Howells, 1973; ***No. = Bräuer, 1988. Subtenses of the facial flatness measurements were not measured directly, but obtained from three sides of a triangle measured using trigonometric formulae: $\cos A = (b^2 + c^2 - a^2)/2bc$; $\sin B = (1 - \cos^2 A)^{1/2}$; subtense $s = b \sin A$.

definded by Howells (1989). At first, C-scores were calculated for all individuals using a grand mean of 42 population sample means (to avoid weighting by different sample numbers), and standard deviation based on the pooled variances of the same population samples. Second, Mahalanobis's generalized distance was applied to the C-score datasets. In this procedure, both size effect and correlation of variables can be removed. Clustering techniques based on the unweighted pair group method and principal co-ordinate analysis were applied to C-score-based Mahalanobis' distance matrix to visualize the intergroup relationships with minimum loss of total information involved in the original distance matrices.

Principal component analysis was also performed for analyzing the pattern of group separation based on the sets of characters or variables, while taking into account the correlation of variables.

RESULTS

Distance analysis based on C-scores

In the first analysis, C-score-based Mahalanobis' generalized distances between every pair of samples were calculated. Figure 1 shows the distance between the Mariana sample and the other samples. The Mariana sample shows close affinities to some of the Southeast Asian, East Asian, and Polynesian samples. Among the Asian samples, the Mariana sample shows closer relationships with southerly distributed population samples than with more northerly inhabiting ones.

The intergroup relationships included in the distance matrix was visualized with minimum loss of the information by applying cluster analysis and principal co-ordinate analysis. Applying the unweighted pair group method clustering algorithm results in the dendrogram shown in Figure 3. The initial split, indicating the greatest dissimilarity, is between a branch containing the Australian and Melanesian samples and all the remaining series with the exception of the Caroline sample. The Andamanese sample is the next to separate from the remaining samples, suggesting the extreme of variability within general East/Southeast Asian populations. All the Polynesian samples other than the Tonga-Samoa sample form a separate branch that splits before all the remaining Asian series cluster. The Nicobarese, the small Neolithic Vietnam sample, Jomonese, Ainu, and Tonga-Samoa samples remain outside the majority of the East/Southeast Asian series. Among Asian series, the East Asian and Southeast Asian samples are divided into subclusters. The Mariana sample is marginally related to the Southeast Asian cluster.

Principal co-ordinate analysis was applied to the same distance matrix used in the cluster analysis. The eigenvalues, the percentage of total dispersion and the level of significance for the first four dimensions are given in Table 3. Figure 3 illustrates the

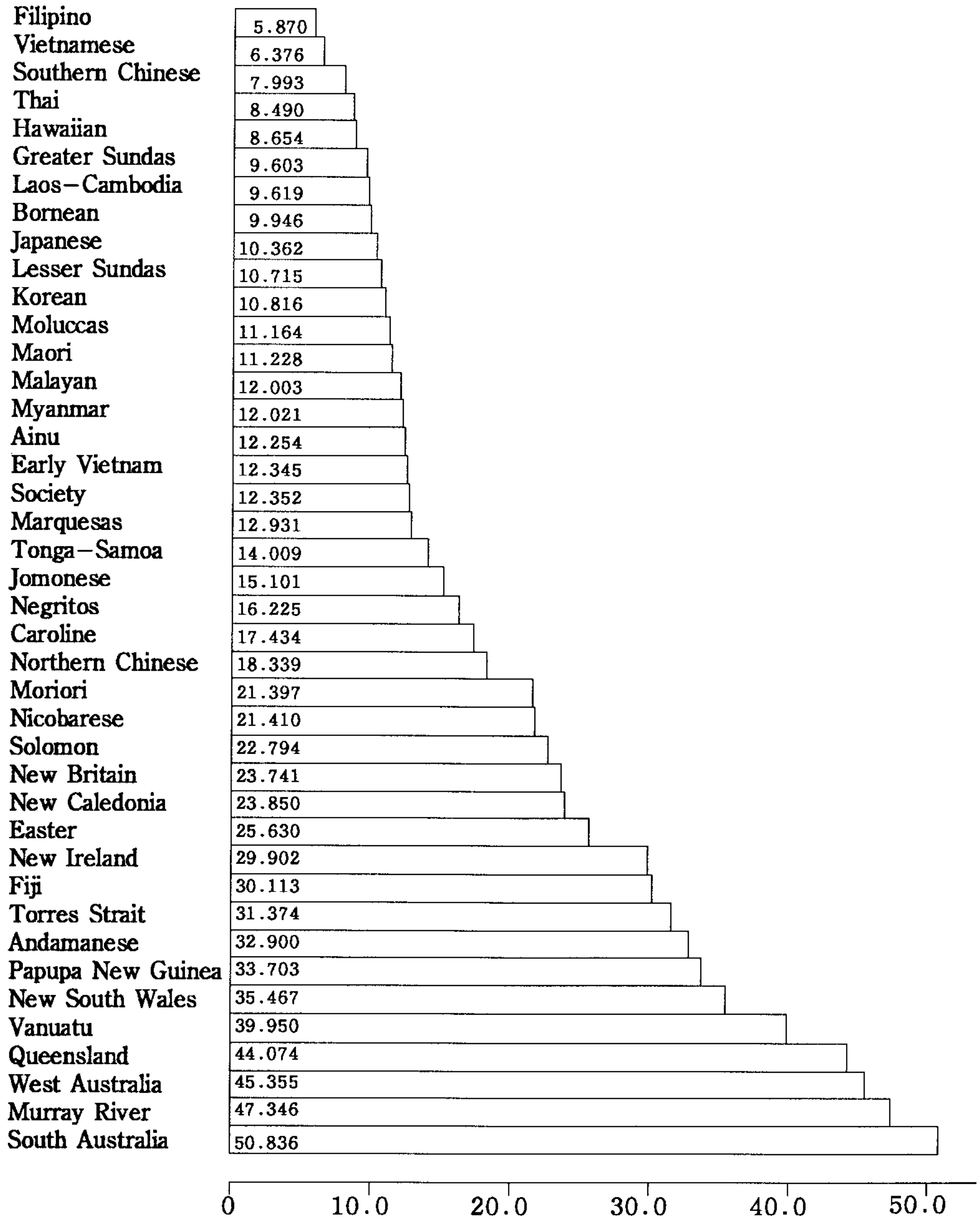

Fig. 1. Distance between the Mariana samples and other samples measured by Mahalanobis' generalized distance based on C-score. Bar length is equivalent to the distance from Mariana sample (given by number).

first two co-ordinates of each sample. It is quite clear that the primary division is one between the Australian-Melanesian samples and one containing other geographical samples, Micronesians, Polynesians, and East/Southeast Asians. This supports Pietrusewsky's (1988, 1990b,c) conclusion that Australians and Melanesians are two branches of one major stem. Within the Melanesian samples, the Fiji sample shows

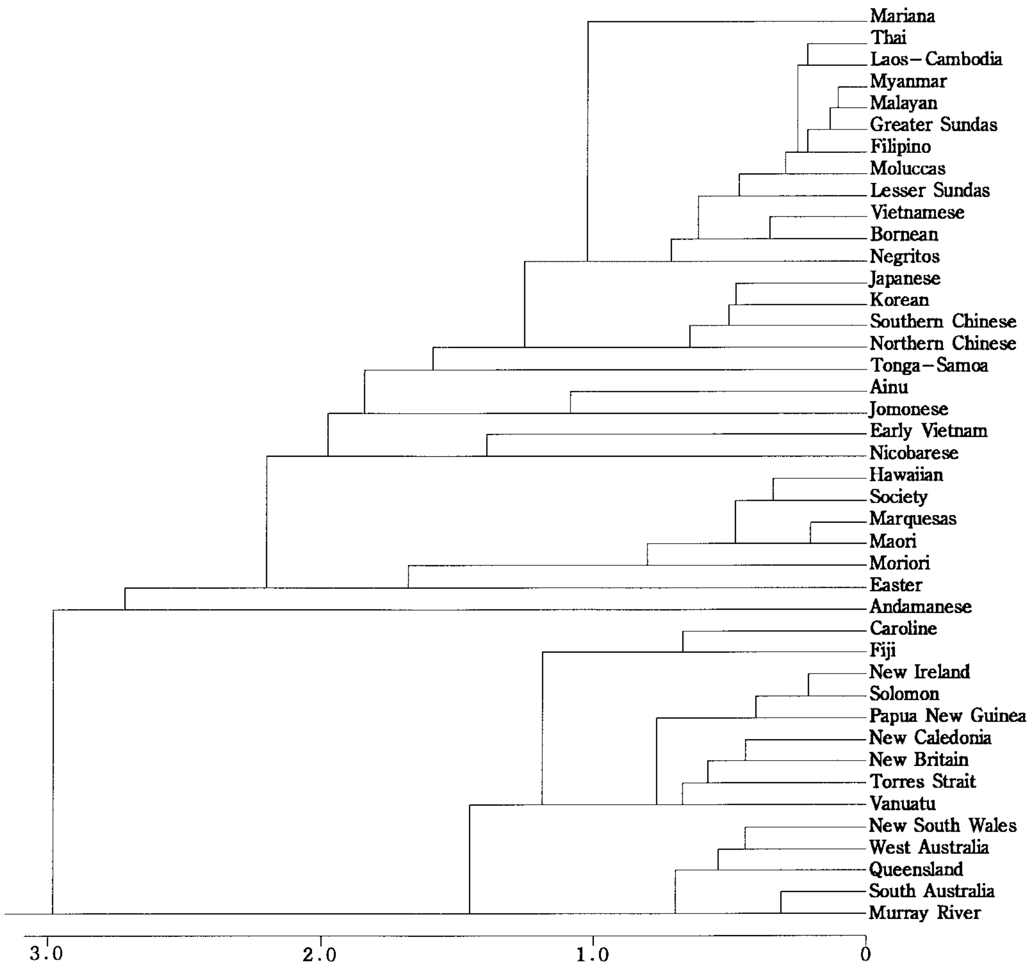

Fig. 2. Result of cluster analysis based on unweighted pair group method applied to C-score–based Mahalanobis' generalized distance.

a more or less different morphological pattern. Among the Polynesian samples, the Easter and Tonga-Samoa samples constitute extremes of the variability of this group. There is much variation within East/Southeast Asian samples, and several groups such as the Ainu and Jomonese samples in the East Asian groups, and the early Vietnam, Andamanese, Nicobarese, and Philippine Negrito series in the Southeast Asian samples fall as outliers to more typical Asian morphologies. In Micronesian groups, the result suggests an isolation of the Caroline sample from the Mariana Islander sample. The Mariana sample together with the East Asian Chinese, Korean, and Japanese samples is plotted at an intermediate position between the Southeast Asian–Jomonese cluster and the Polynesian cluster.

Principal component analysis

Principal component analysis was performed on the C-scores, in the hope that the resulting components would more purely reflect shape factors only. In the present study, a pooled correlation matrix calculated from all individuals with no missing value was used. Table 4 gives the basic information of the first nine components having eigenvalues greater than 1.0. By removing size as a factor, the crude correlations are lowered, which makes the factor loadings

TABLE 3. Results of principal coordinate analysis (contribution rate and coordinate scores for each sample)

	Dimension			
	1	2	3	4
Eigenvalue	5.1887	1.8256	0.2665	0.1158
Proportion	0.7015	0.2468	0.0360	0.0157
Cumulative proportion	0.7015	0.9483	0.9843	1.0000
1 Mariana	−0.3580	0.0602	0.1091	−0.0413
2 Caroline	0.0918	0.2458	0.0328	0.0565
3 Japanese	−0.2945	0.1399	−0.0425	0.0426
4 Ainu	−0.0504	0.1058	0.0854	−0.1120
5 Jomonese	−0.1392	−0.1998	0.1302	−0.1315
6 Northern Chinese	−0.4179	0.2315	−0.1143	0.0735
7 Southern Chinese	−0.4048	0.0362	0.0503	0.0521
8 Korean	−0.5134	0.0500	−0.0474	0.0240
9 Thai	−0.3693	−0.1449	−0.0278	0.0073
10 Vietnamese	−0.2953	−0.0948	0.0868	0.0443
11 Early Vietnam	−0.0834	−0.0186	0.2555	0.0032
12 Laos-Cambodia	−0.3904	−0.2413	−0.0189	−0.0186
13 Myanmar	−0.2182	−0.2297	−0.0501	0.0085
14 Malayan	−0.2342	−0.2000	−0.0772	0.0093
15 Andamanese	−0.0489	−0.4128	−0.0922	0.0705
16 Nicobarese	0.1034	−0.1501	0.1178	0.1239
17 Bornean	−0.1286	−0.1241	0.0666	0.0567
18 Filipino	−0.2566	−0.1538	0.0336	−0.0186
19 Negrito	−0.2124	−0.3637	0.0398	−0.0044
20 Greater Sundas	−0.2766	−0.2268	−0.0263	−0.0056
21 Lesser Sundas	−0.1522	−0.1495	−0.0574	−0.0283
22 Moluccas	−0.3543	−0.2157	−0.0569	0.0014
23 Hawaii	−0.2643	0.2751	0.0421	−0.0272
24 Tonga-Samoa	−0.3788	0.0081	−0.0934	−0.1192
25 Marquesas	−0.1619	0.3499	−0.0582	−0.0266
26 Easter	0.1645	0.4649	0.1275	0.0271
27 Society	−0.0949	0.3023	−0.0240	0.0052
28 Maori	−0.1188	0.3603	−0.0142	−0.0421
29 Moriori	−0.2278	0.4507	−0.1219	−0.0574
30 Papua New Guinea	0.3844	−0.0063	−0.0961	0.0566
31 Torres Strait	0.4377	0.0089	−0.0302	−0.0299
32 Vanuatu	0.5720	−0.0142	−0.0159	0.0123
33 New Caledonia	0.3596	0.0546	0.0633	0.0265
34 New Britain	0.3075	−0.0142	0.0393	−0.0006
35 New Ireland	0.2959	0.0099	−0.1162	0.0229
36 Solomon	0.2523	0.0328	−0.0616	0.0313
37 Fiji	0.3279	0.2244	0.0508	0.0888
38 New South Wales	0.5432	0.0016	0.0018	−0.0205
39 South Australia	0.7082	−0.0294	−0.0654	−0.0429
40 Queensland	0.6064	−0.2325	0.0417	−0.0589
41 West Australia	0.6049	−0.1158	−0.0512	−0.0312
42 Murray River	0.6851	−0.0747	−0.0152	−0.0279

(correlations of measurements with components) more specific (Howells, 1986). The first nine components, retained here, carry some 75% of the total measurement information in undistorted form. The first nine principal component scores for each sample are given in Table 5.

If the eigenvalues greater than 2.0 and less than −2.0 are taken into account, the first nine components can be interpreted as follows. The 1st principal component (PC) separates groups most importantly on the basis of the narrow cranial vault width, especially frontal region, low cranial vault height (basion-bregma height), prominence of facial length, and weakness of frontal as well as simotic facial flatness. Differences in the length of the cranial vault and midfacial width including maxilloalveolar width are responsible for the group separation achieved in the 2nd PC. Discrimination produced in the 3rd PC is based primarily on narrow frontal and zygomaxillary breadth, short sagittal frontal arc, high upper face and nose, and prominence of zygomaxillary and simotic subtenses. Dimensions of the cranial base length, the sagittal parietal arc and chord, and zygomaxillary chord are responsible for separation produced in the 4th PC. The 5th PC stresses the prominence of cranial base length, sagittal parietal arc, upper facial height, orbital height, and nasal height with contrast to the maximum occipital width and the saggital occipital arc and chord. The 6th PC suggests relatively wide cranial vault, especially in frontal region, not flat zygomaxillary in contrast with the cranial length and middle facial width. The 7th PC indicates a wide frontal chord and high orbit, and the prominence of the mastoid process, together with a lack of the protrusion of cranial base and facial length, narrow interorbital breadth and nasal width as well as horizontal breadth of the nasalia. The 8th PC accents a wide occipital breadth, long frontal arc and chord, and wide maxilloalveolar breadth and mastoid process, with relatively small size of minimum frontal breadth, interorbital breadth, and low orbit. The character set of long forehead and wide middle facial region, together with narrow auricular and occipital breadth, and short parietal arc is represented by the 9th PC.

Fig. 3. Two dimensional display of the sample affinities by principal coordinate analysis based on the information in Table 3.

A plot of the samples on each principal component based on the PC scores is presented in Figure 4. The 1st PC separates the Australian and Melanesian samples from all the other samples. Among the latter samples, the Easter, Andamanese, Nicobarese, and to a lesser extent, Jomonese and Ainu samples show weak Australian-Melanesian characteristics. The Micronesian samples show close affinities to East Asian samples. The Australian and the Melanesian samples group with the Polynesian samples in the 2nd PC with the exception of a few samples. In this component, the Fiji sample is separated from other Melanesian samples, and the Tonga-Samoa and Easter samples from other Polynesian samples. In the Southeast Asian samples, the Nicobarese and early Vietnam samples show similar characteristics to those of the Australian, Melanesian, and Polynesian samples. The Mariana sample shares similar characteristics with those of the East/Southeast Asian samples, while the Caroline sample shows close affinities to the Australian, Melanesian, and Polynesian samples. The 3rd PC characterizes the great variation within the East Asian samples. The Jomonese and Ainu samples again occupy a separate isolated grouping. The early Vietnam sample is closely related to the Jomonese-Ainu samples. The Mariana sample and the Caroline sample are again separated from each other. The 4th PC characterizes the Polynesian craniofacial traits. The Bornean, Negrito, Andamanese, and Nicobarese samples fall out of the range of all the

TABLE 4. Eigenvalues and eigenvectors by principal component analysis

Item	Principal component 1	2	3	4	5	6	7	8	9
1 M1	0.15632	0.36339	−0.04999	−0.06526	0.00189	−0.29134	0.08044	0.00968	0.01220
2 M1d	0.10155	0.36828	−0.02536	−0.09064	0.01402	−0.34227	0.05319	−0.08372	0.02783
3 M5	0.02304	0.01321	−0.10855	−0.39055	0.20268	−0.17198	−0.36767	−0.01445	−0.19761
4 M8	−0.29564	−0.06191	−0.06233	−0.08207	−0.09807	0.23587	−0.02546	0.08460	−0.07373
5 M9	0.04328	0.02054	−0.30055	0.10773	0.02175	0.34349	0.14842	−0.29218	−0.05666
6 M10	−0.26500	−0.01987	−0.14120	0.07855	0.02699	0.28026	0.00855	−0.13386	−0.06444
7 M11b	−0.24362	−0.17571	−0.15837	−0.03563	−0.02510	−0.04115	0.06489	0.18473	−0.23895
8 M12	−0.04843	−0.01558	0.03173	0.08536	−0.33977	0.00819	0.13781	0.27156	−0.32088
9 M17	−0.27320	0.08632	−0.09126	−0.07414	0.07803	−0.00750	−0.17285	0.06017	−0.08230
10 M26	−0.09723	0.29128	−0.21662	0.02457	0.10668	0.20484	0.01443	0.22189	0.38133
11 M27	−0.07932	0.18537	0.05665	0.49101	0.20720	−0.09293	−0.06245	0.01266	−0.20866
12 M28	−0.10144	0.22006	0.12113	−0.16130	−0.45717	−0.12922	0.11513	−0.17054	0.03787
13 M29	−0.14993	0.25541	−0.16248	−0.08917	0.15087	0.13634	−0.02473	0.24897	0.39210
14 M30	−0.02617	0.23970	0.06074	0.48311	0.17058	−0.15419	−0.00056	−0.02186	−0.19383
15 M31	−0.19718	0.13512	0.07830	−0.18716	−0.41721	−0.04108	−0.02640	−0.16686	0.02870
16 M40	0.23517	0.00973	0.03723	−0.19203	0.08363	−0.01223	−0.28303	0.16201	−0.10844
17 M43	0.22521	−0.10652	−0.32210	−0.04595	0.08238	−0.00806	0.19236	−0.09336	0.01161
18 M43(1)	0.25469	−0.12252	−0.26409	−0.04544	0.04328	−0.05859	0.24067	−0.09111	−0.00084
19 No. 43c	0.25960	0.05408	0.04607	−0.06854	0.02705	0.15504	−0.05852	−0.08000	−0.01665
20 M45	−0.14707	−0.20702	−0.23516	−0.09266	0.01035	−0.18827	0.12276	0.19380	−0.26578
21 M46	−0.11940	−0.30476	−0.04249	0.13947	−0.09865	−0.23369	−0.17943	−0.03485	0.32623
22 No. 46b	−0.01377	−0.30455	−0.04648	0.20327	−0.13790	−0.25390	−0.12746	−0.04478	0.35598
23 No. 46c	0.15009	−0.02812	0.21151	−0.08455	0.01808	0.23903	−0.15549	0.17057	0.09010
24 M48	−0.16902	−0.08131	0.32379	−0.08700	0.28835	−0.08730	0.11086	−0.15951	0.10175
25 M49a	0.13609	−0.05757	−0.18660	0.16207	−0.16044	0.04150	−0.22466	−0.35572	0.08721
26 M51	0.19264	−0.11589	−0.11661	−0.15149	0.11397	−0.13175	0.37425	0.04823	0.02172
27 M52	−0.11071	−0.09452	0.16539	−0.14232	0.20208	0.10787	0.17678	−0.32582	−0.05666
28 M54	0.15311	−0.10171	−0.05454	0.10440	−0.14983	−0.10030	−0.21050	0.13498	−0.02607
29 M55	−0.19121	−0.13090	0.24685	−0.12793	0.26819	−0.11783	−0.02587	−0.16830	0.02414
30 M57	0.22529	−0.06084	0.10087	0.07775	−0.06710	0.18735	−0.25244	−0.16939	−0.12428
31 No. 57a	0.21314	0.02079	0.21559	−0.06183	−0.01117	0.19926	−0.06319	0.09139	−0.09866
32 M61	0.09234	−0.22226	0.05780	0.06699	0.08827	−0.04009	−0.01158	0.30547	0.09082
33 H-MDH	0.03307	−0.09132	0.30009	0.08763	−0.00724	−0.01598	0.30799	0.05723	0.11364
34 H-MDW	0.14716	−0.00691	0.24474	0.06128	−0.14617	0.15741	0.23044	0.20441	0.06749
Eigenvector	7.53009	4.10391	3.09910	2.37768	1.96577	1.82653	1.70304	1.52124	1.22684
Proportion	0.22147	0.12070	0.09115	0.06993	0.05782	0.05372	0.05009	0.04474	0.03608
Cum. prop.[a]	0.22147	0.34218	0.43333	0.50326	0.56107	0.61480	0.66489	0.70963	0.74571

[a] Cumulative proportion.

other groups in this component. The PC from the 5th to the 9th are good at making some sample distinctions but are perhaps less so at describing groups or populations in a geographical sense. The 5th PC opposes the northern Chinese sample to the Jomonese sample. The 6th PC is the Andamanese and to a lesser extent the Philippine Negrito factor. The mainland and island Southeast Asian samples are opposed to the East Asian samples except for the Greater Sunda sample in the 7th PC. The 8th and 9th PC characterize the craniofacial pattern of the Andamanese sample and the Jomonese sample respectively.

The two Micronesian samples, the Mariana and the Caroline samples, are separated by 2nd, 3rd, and 5th PCs. In these components, the Mariana sample shows closer affinities to East/Southeast Asian groups. On the other hand, the Caroline sample shares more similar craniofacial characteristics with the Melanesian samples than the Mariana sample. The Mariana sample falls within the Melanesian variation in the 6th to 9th components. However, the affinities between the Mariana sample and the Melanesian samples in these components are not specific to these two groups.

Finally, Figure 5 uses multidimensional plots by Andrews (1972) to display information obtained by principal component analysis. In this figure, the first nine components modulate a plotted curve for each group, which allows a visual impression of the degree of conformity among them. This method can remove certain limitations of clustering or of having to plot the relative

TABLE 5. Principal component scores for each sample

	Name of sample	1st PC	2nd PC	3rd PC	4th PC	5th PC	6th PC	7th PC	8th PC	9th PC
1	Mariana	−2.0006	−0.5482	−1.1291	−0.4797	−0.2698	−0.5918	−0.2519	0.2439	−0.3509
2	Caroline	−0.1932	1.3256	0.4399	−0.0469	1.1272	−0.9543	−0.0135	−0.1069	−0.1732
3	Japanese	−2.0360	0.0271	0.9206	0.0100	−0.3252	−0.2741	0.9529	−0.0182	0.1290
4	Ainu	−0.0238	−0.1321	−1.2577	−1.1400	−0.5619	−0.6480	0.4395	0.3377	−0.3296
5	Jomonese	−0.3732	−1.0244	−2.1375	0.3055	−1.3440	0.3762	0.3801	−0.2699	−1.5997
6	Northern Chinese	−2.8728	−0.1597	1.8586	−0.2427	1.0120	−0.8044	1.1370	−0.5138	0.3790
7	Southern Chinese	−2.6174	−0.1312	0.0281	0.6113	−0.2779	−0.7320	−0.0268	−0.5141	−0.0622
8	Korean	−2.9236	−1.0624	0.7489	−0.0211	−0.4488	−0.4187	0.8188	−0.2367	0.3148
9	Thai	−1.6818	−1.5692	0.0343	0.5033	−0.0067	0.4888	−0.2522	0.4291	0.8059
10	Vietnamese	−1.5496	−0.7641	−0.5820	0.8635	0.1386	−0.5973	−1.1888	−0.1515	0.6656
11	Early Vietnam	−0.7600	1.0145	−1.9456	0.9905	−0.7918	−1.2746	−0.5635	−0.3583	−0.0492
12	Laos-Cambodia	−1.5530	−2.0464	−0.4893	0.6986	−0.2969	0.6641	−0.3503	−0.1685	0.3185
13	Myanmar	−0.7325	−1.3259	0.1430	0.7597	−0.1634	0.8459	−0.1723	−0.1951	0.5751
14	Malayan	−0.9380	−1.2884	0.4249	0.6384	−0.2561	1.1928	−0.0623	0.3045	0.3565
15	Andamanese	0.2975	−0.8070	0.8513	1.5544	−0.6255	2.7487	−1.2070	−1.3270	0.7122
16	Nicobarese	0.4600	0.7822	0.2203	2.0054	−0.4154	−0.6394	−1.3332	−0.2496	0.6949
17	Bornean	−0.7996	−0.0607	−0.3802	1.3215	−0.4680	−0.0483	−0.6114	−0.4296	0.2646
18	Filipino	−1.1031	−1.0099	−0.6744	0.3730	−0.6038	0.3402	−0.4269	0.0075	0.1113
19	Negrito	−0.6144	−0.9867	−0.9198	1.3094	−0.4611	1.3737	−0.8189	−0.6036	0.1324
20	Greater Sundas	−0.9302	−1.7644	−0.1432	0.5277	−0.3769	0.6370	−0.5285	−0.2337	0.4644
21	Lesser Sundas	−0.5241	−0.8117	0.0726	0.2115	0.0478	0.9328	0.4451	−0.3284	−0.2542
22	Moluccas	−1.3172	−2.0709	0.5356	0.4835	−0.9322	0.5905	−0.4333	0.1828	0.1880
23	Hawaii	−1.9385	0.6605	−0.7110	−1.8745	0.4153	−0.0193	−0.7147	0.2211	0.1770
24	Tonga-Samoa	−1.6451	−2.0287	−0.6995	−1.5693	0.6525	1.3192	0.5783	−0.0576	−0.0545
25	Marquesas	−1.2114	0.4460	0.4739	−2.0600	0.2125	−0.6110	0.6145	0.5772	0.7799
26	Easter	0.0967	2.4603	−0.2710	−1.8878	0.6819	−1.4780	−1.3641	0.4753	−0.0880
27	Society	−1.0942	1.0974	0.5230	−1.5546	0.7756	0.0338	−0.1599	0.1378	−0.1467
28	Maori	−1.1152	0.6040	−0.0181	−1.9700	0.0962	−0.8409	0.6184	0.4499	−0.0962
29	Moriori	−1.5368	−0.1103	0.7783	−2.8779	0.4793	−1.0319	1.0370	−0.2989	−0.0789
30	Papua New Guinea	2.1002	0.5814	1.5398	0.0981	0.1533	0.3041	−0.4735	−0.2550	−0.0102
31	Torres Strait	2.3750	0.4906	0.0592	−0.1363	0.2073	−0.0235	0.3893	0.0831	−0.6135
32	Vanuatu	3.1252	0.7446	0.4901	0.7684	0.2237	−0.7874	0.3338	1.0282	−0.6354
33	New Caledonia	1.7351	1.1202	−0.0905	0.1148	−0.2105	−0.4195	−0.6099	0.4294	−0.0046
34	New Britain	1.5980	0.0577	−0.2584	0.4287	−0.1671	−0.8108	−0.0900	0.5240	−0.8070
35	New Ireland	1.5104	0.3529	1.1955	0.2615	0.3773	0.4717	0.7328	0.1246	−0.5444
36	Solomon	1.2338	0.5221	1.0264	0.1952	−0.0514	0.0960	0.4050	0.0545	−0.2455
37	Fiji	0.9092	2.6791	0.7892	0.1303	0.2590	−0.4780	−0.1426	−0.2482	0.0172
38	New South Wales	2.8581	1.5173	−0.2438	−0.0280	0.4104	0.1869	0.7854	0.5000	−0.1435
39	South Australia	4.4594	0.7955	0.3473	−0.4535	0.1843	0.0549	0.5859	0.4168	0.1554
40	Queensland	3.6091	0.7490	−1.4917	0.7332	0.6747	0.7910	0.5055	−0.2635	−0.3914
41	West Australia	3.6690	0.6968	0.0614	−0.0940	0.4904	0.3354	0.2079	−0.2456	−0.1287
42	Murray River	4.0485	0.9775	−0.1196	0.5388	0.4350	−0.3006	0.8287	0.5463	−0.4339

positions of groups on only two or three axes at a time. The complexity is, however, such that interpretation of morphology is impossible. In this figure, shaded zone is an envelope of the extreme values at any point of each geographical samples. In the cases of the Melanesian, Polynesian, and East/Southeast Asian groups, the samples such as the Fiji, Tonga-Samoa, Easter, Andamanese, Nicobarese, Negrito, early Vietnam, Jomonese, and Ainu are regarded as the extremes of variability within each geographical group. The linear shaded zone in Figure 5 shows the values excluding these extreme samples in each geographical group. The zone of dotted shadow indicates the values including these extreme samples.

The curve of the Mariana sample clearly deviates in direction in the Australian and Melanesian curve, but not the Polynesian, East/Southeast Asian curve including the extreme samples in each group. However, the Mariana sample clearly disagrees with the typical geographical groups in each region. On the other hand, the Caroline curve follows in greater degree the zone of Melanesian groups. At the same time, this sample agrees with the Polynesian samples over most of the range.

DISCUSSION

Howells (1970, 1973) and Pietrusewsky (1990b) found a marked separation between western Micronesia and central, as well as

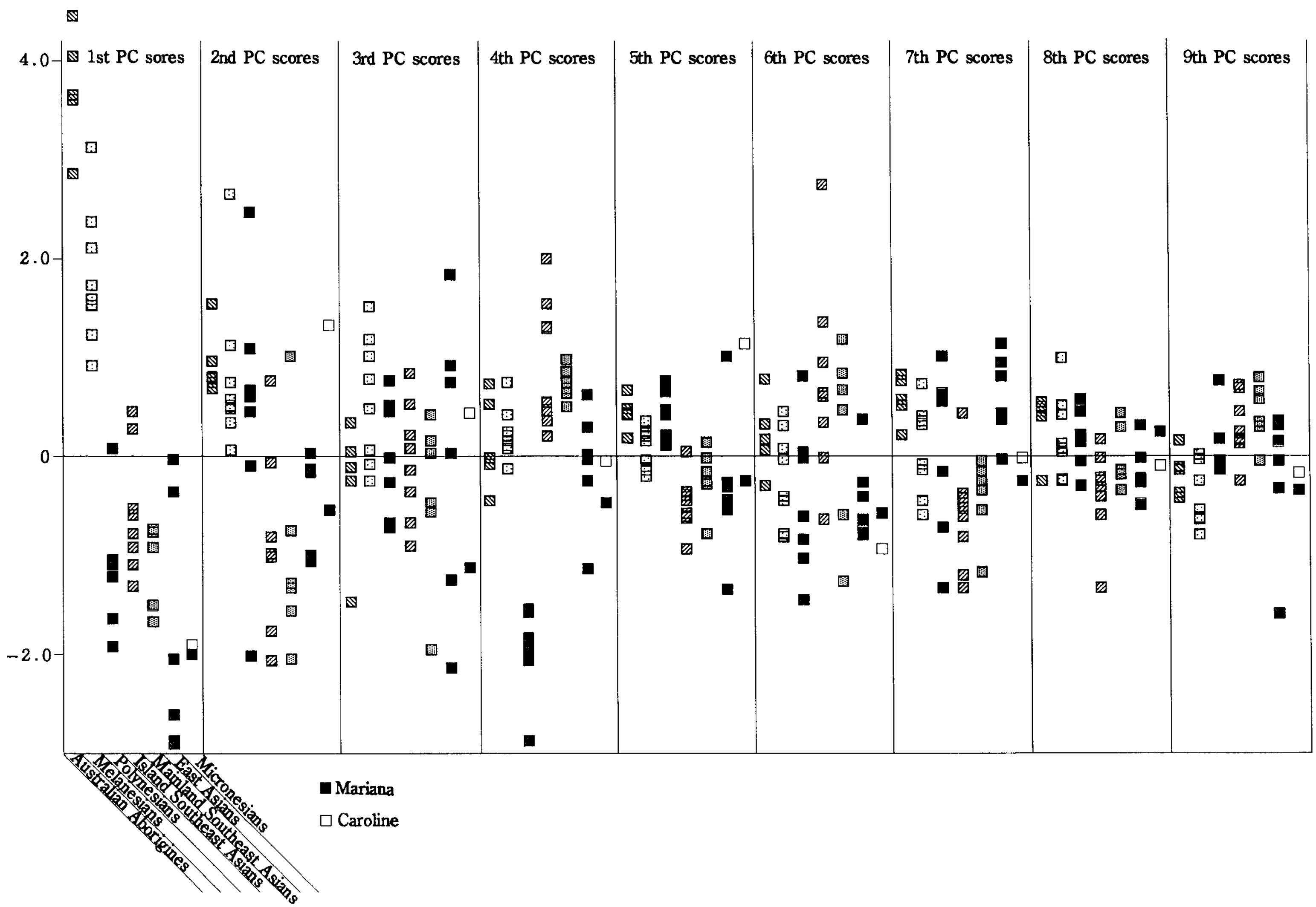

Fig. 4. Plot of the first nine principal component scores for each sample based on the information in Table 5.

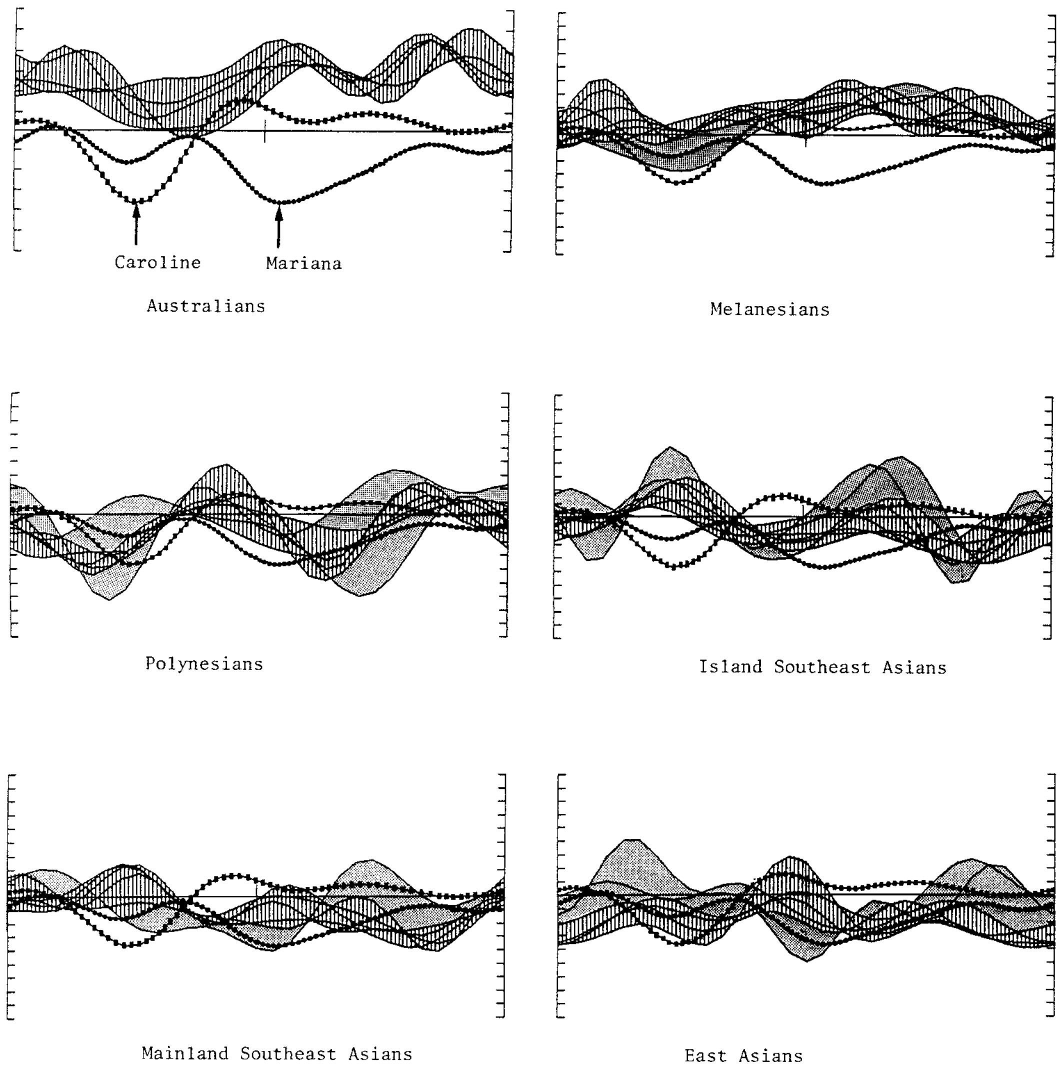

Fig. 5. A multidimensional plot (Andrews, 1972) for the Mariana (circle), Caroline (square), and each geographical group (shading zone) of the first nine principal component scores simultaneously. These are entered in a Fourier trigonometric function:

$$f_t(x_1, x_2, \ldots, x_p) = x_1/2 + x_2 \sin t + x_3 \cos t + x_4 \sin 2t + x_5 \cos 2t + \cdots + x_p \cos((p-1),t/2)$$

where p is an odd number. The values of t (thus of f) are periodic over the range of -2 to $+2$. The value of f is plotted for values of t along this scale to form the curve for each group.

eastern Micronesia, or nuclear Micronesia as viewed from anthropometric and craniofacial features. A dental study shows the same dichotomous nature of Micronesian populations (Hanihara, 1992). Linguistic and archaeological evidence also shows a west-east division of Micronesia (Bender, 1971; Bellwood, 1979; Craib, 1983; Intoh, 1997). Regarding this division, Pietrusewsky (1990b) confirmed craniometrically the Ponapean–eastern Melanesian association. However, he argued that this association was evidence of contact between Melanesians and nuclear Micronesians, not necessarily evidence of a Melanesian origin of Ponapeans. On the other hand, Bellwood (1979) suggests that

nuclear Micronesians are close cousins to Polynesians based on linguistic studies. The present findings re-confirm the west-nuclear divisions of Micronesian craniofacial features. Moreover, there may be a Caroline-Melanesian/Polynesian association as suggested by Howells (1970).

The present findings re-confirm the craniofacial association of the Mariana Islanders with East/Southeast Asians as already pointed out (Pietrusewsky, 1990b,c; Turner, 1990a; and many others). A relatively loose association of the Mariana Islanders with some Polynesians is parallel to those proposed from genetic analyses (Serjeantson, 1989; Serjeantson and Hill, 1989) as well as cranial non-metric and facial flatness studies (Ishida and Dodo, 1993; Ishida, 1993).

The present results suggest that there is much variation within recent general East/Southeast Asian populations, and several groups fall as outliers to more typical East/Southeast Asians, like Ainu, Easter Islanders, Andamanese, Nicobarese, and certainly Philippine Negritos as pointed out by Lahr (1995). If we include small series of the prehistoric populations, Jomonese and early Vietnam, their morphological patterns also constitute the extremes of the present East/Southeast Asian craniofacial morphological variability. Fiji and Tonga-Samoa Islanders do not necessarily fall within a single branch of the respective Melanesian and Polynesian groups. Fiji and Tonga-Samoa Islands are suggested as one possible region of the first colonization from where the ancestors of recent Polynesians could have originated (Green, 1981; Kirch, 1982; Pietrusewsky, 1985; Bellwood, 1989). Fijians, most remote from the western Melanesian center, have, moreover, retained much greater biological relationships with Polynesians, intensified through continuing intermarriage with Tongans (Bellwood, 1989).

As illustrated in Figure 5, Mariana Islanders do not show strong craniofacial similarity to any typical or predominant populations in each geographical area. However, the curve of Mariana Islanders is included in greater part in the zone of the populations including the so-called "minorities" such as Ainu, Andamanese, Nicobarese, and Philippine Negritos, prehistoric populations (Jomonese, early Vietnam), and populations with much complex historical-biological backgrounds like Fiji and Tonga-Samoa Islanders.

Taking all of these into account, the present findings suggest that the craniofacial characteristics of Mariana Islanders reflect, at least in part, an admixture of a generalized Asian element with incomers of northern origin in East Asia, sensu lato. The results obtained do not favor the significant Melanesian or Jomonese input to western Micronesia proposed by genetic and craniofacial morphological studies (Serjeantson, 1989; Ranford, 1989; O'Shaughnessy et al., 1990; Brace et al., 1989, 1990; Brace and Hunt, 1990; Brace and Tracer, 1992). However, the Melanesian or Jomonese elements as generalized characters of Macro-Asian-Pacific populations cannot be ignored completely in the craniofacial characteristics of Mariana Islanders. Brace et al. (1990) point out the large dental size of Guamanians is compatible with those of Melanesians.

While Melanesian influence cannot be ruled out, it is unlikely that the characteristics of the Mariana Islanders arose as the result of transformation of the pattern visible in Melanesia.

ACKNOWLEDGMENTS

I am deeply grateful to Professor D.B. Hanson of the Forsyth Institute for Advanced Research and Professor M. Pietrusewsky of the Department of Anthropology, the University of Hawaii-Manoa for inviting me to participate in the symposium, "Prehistoric Human Skeletal Biology in Island Ecosystems: Current Status of Bioarchaeological Research in the Marianas Archipelago," at the 64th annual meeting of the American Association of Physical Anthropologists held in Oakland, California, in 1995.

I express my sincere gratitude to Dr. T. Molleson and R. Kruszynski of the Natural History Museum (London); Dr. R. Foley and Dr. M. Bellatti of the Department of Biological Anthropology, University of Cambridge; Professor A. Langaney and Dr. Miya Awazu Pereira da Silva of Laboratoire d'Anthropologie biologieque, Musée de l'Homme, Paris; Dr. J. Specht, Dr. P. Gordon, Dr. L.

Bonshek, and Dr. N. Goodsell of the Department of Anthropology, Australian Museum; Professor J. Stone and Dr. D. Donlon of the Department of Anatomy and Histology, the University of Sydney; Mr. D. Henley of the New South Wales Aboriginal Land Council; Dr. M. Chow, a dentist in Sydney, Professor M. Hanihara of the School of Languages, Macquarie University; Dr. C. Pardoe and Dr. G.L. Pretty of the Department of Anthropology, South Australian Museum; Professor M. Pietrusewsky; Dr. Y.H. Sinoto of the Department of Anthropology, B.P. Bishop Museum; Professor B. Endo and Professor T. Akazawa of the Department of Anthropology, Faculty of Science, the University of Tokyo; for their kind permission to study the materials under their care.

I am deeply indebted to Professor Y. Dodo of the Department of Anatomy, Tohoku University School of Medicine, and Professor H. Ishida of the Department of Anatomy, School of Medicine, Sapporo Medical University, for their encouragement, invaluable support, and critical advice.

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